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RESEARCH ARTICLE

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Investigation of the vegetation structure, diversity and composition in the tropical semi-evergreen forests of Northeast India

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Abstract
The Himalayan forests are highly threatened due to anthropogenic pressures ranging from agriculture intensification, deforestation, hydropower development, etc. The present study attempts to document the floristic diversity, composition and structure of vegetation communities in the tropical semi-evergreen forest of North Cachar Hills in Assam. A one-time assessment was made during the peak growing season in a 4000 m^2 forest area to make an inventory of vegetation structure by using the nested quadrat method. A total of 445 individuals belonging to 52 tree species were recorded from the overstorey, while 161120 individuals belonging to 72 species were recorded from the understorey vegetation. The forest stand structure exhibited a reverse J-shaped population curve, and most tree species showed no regeneration (57%), while others showed either good (23%) or poor (17%) regeneration. This study highlights that the understorey vegetation is as important as the overstorey vegetation with respect to species diversity. This study can serve as a baseline for assessing the impacts of different natural and anthropogenic threats on biodiversity in the study area. Additionally, this study highlights the need to conserve the natural forests of Northeast India and protect them from different threats.

Keywords
Anthropogenic, biodiversity, endemic, forest, threatened

Introduction

In recent years, the Northeastern forests of India have witnessed increasing anthropogenic disturbances, including agriculture intensification, deforestation, hydropower development, climate change, rampant and unplanned urbanization, etc. (Pandit 2017). The high anthropogenic pressures are leading to negative effects on species diversity and community structure and loss in ecosystem services of the Northeastern Indian forests (Majumdar et al. 2012). The Northeast region of India includes the states of Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim and Tripura. Geographically, Arunachal Pradesh and Sikkim constitute the Eastern Himalayan region, while other states form an extension of the Eastern Himalayan mountain systems (Pandit 2017; Pandit et al. 2014). Assam, while being part of this mountain system also forms a sort of ecotone region due to geographical links with Khasia and Garo hills and also with Bangladesh and Bhutan (Baishya 1999).

The structure and composition of a forest vary across topographical space, resulting in variation in composition in all the strata (canopy, overstorey, understorey and forest floor). The main factors responsible for this variation in the forest are the differences in micro-climate driven by temperature and precipitation (Walck et al. 2011). The diversity in each vegetation strata is important to maintain the resilience and resistance of forest ecosystems (Nikinmaa et al. 2020). Several earlier studies in the Northeastern Indian forests have focussed on documenting the native species diversity, population structure and regeneration status of species in different natural forests of Assam, Meghalaya and adjoining regions (Kumar et al. 2006; Borah and Garkoti 2011; Borah et al. 2014; Sarkar and Devi 2014; Saikia and Khan 2016; Borogayary et al. 2018; Malunguja et al. 2021; Nautiyal and Manish 2024). However, most of these studies have focussed mainly on the assessment of overstorey species diversity, thereby neglecting the vegetation composition and structure of understorey shrub assemblages (Borah and Garkoti 2011; Sarkar and Devi 2014; Saikia and Khan 2016). Even the study of the biological process of plant invasion gets neglected if studies are only conducted with the focus of documenting overstorey vegetation, as most of the invasive plants in the Northeast Indian region belong to the herb strata (Saikia et al. 2017). Already, there have been reports that the spread of invasive plant species such as *Lantana camara* L., *Chromolaena odorata* (L.) R.M.King & H.Rob. in the understorey of tropical evergreen forests of Northeast India is creating manifold problems, including changes in nutrient cycling, regeneration ability of native species, habitat loss of endemic species, changes in species diversity, etc. (Rai and Singh 2021). Controlling invasive species is not a short-term effort, it requires detailed monitoring, surveillance and research into long-term control options (Larson et al. 2011). Controlling understorey vegetation, especially invasive, can effectively safeguard tree growth and overstory development (Zhang et al. 2016). Further, understorey communities may act as drivers of overstorey succession and nutrient cycling (Su et al. 2019). Therefore, understanding the richness and composition of understorey vegetation is crucial because it contributes significantly to the overall floristic diversity of the community and is essential to the structure and operation of forest ecosystems (Su et al. 2019). This study attempts to fill this literature gap by studying both the understorey and overstorey

vegetation concerning their composition, structure, and diversity in the Cachar hills of Assam, Northeast India. The Cachar hills of Assam are interesting as they connect the Khasia-Jaintia hills of the Northeast Indian region. Though these hills have unique floristic elements because of the ecotone characteristics, the primary forests are being denuded and degraded due to different anthropogenic activities, including slash-and-burn farming (Saikia 2011). This study was undertaken to analyse the vegetation composition and structure of the tropical semi-evergreen forest of the Cachar hills in Assam to document and identify the present ecological status of the native forests in the area.

Material and methods

Study area

The present study was carried out in North Cachar hills along the river Kopili in Karbi-Anglong and Dima Hasao Sub-Division of North Cachar Forest Division in Assam (Fig. 1). The forests within the study stretch consist of 2B/C2 Cachar tropical semi-evergreen forests and 4E/RS1 Tropical Riparian fringing forest types (Fig. 2; Champion and Seth 1968). Dima Hasao and Karbi Anglong are the two hill districts of Assam, which were earlier called North Cachar Hills. They are well known for their unique and rich biodiversity and tribal populations. The Kopili river is the south bank tributary of Brahmaputra, which originates in the Meghalaya plateau and flows between the Karbi Anglong and Dima Hasao districts. The area receives high annual rainfall between June and August, with an average annual rainfall of 1500 mm to 3750 mm. The temperature ranges from 5 °C to 32 °C, and the climate is warm and humid throughout the year. The North Cachar hills form a part of the Indo-Burma global biodiversity hotspot and constitute the foothills of the Indian Himalayan region. Reportedly, the total forest cover of the region is approximately 63777 hectares (NCHAC 2021). The forests are dominated by *Dipterocarpus*, *Artocarpus*, and *Gluta* species.

Vegetation sampling design

Vegetation sampling was carried out during the monsoon season (peak growing season) in September 2014 using the standard belt-transect and nested-quadrat method (Curtis and McIntosh 1950) in the non-protected forest areas of North Cachar forest range. A total of four transects were used in the field sampling, where the dimension of each transect was 200 m long and 10 m wide. Each transect was placed at an interval of 7–8 km perpendicular to the road from south Panimore-Patherkore to Longphu-Digram in North Cachar forest range (Fig. 1). Along each transect, ten 10 m × 10 m nested quadrats were placed randomly for analysing the structure and composition of different vegetation strata and understorey and overstorey vegetation (trees, shrubs, climbers and herbs). Trees (woody plants with a circumference at breast height (cbh) of at least 31.4 cm) were sampled in a 10 × 10 m quadrat, whilst shrubs and saplings (woody plants with a circumference of at least 10 cm to ≤31.4 cm cbh) were sampled

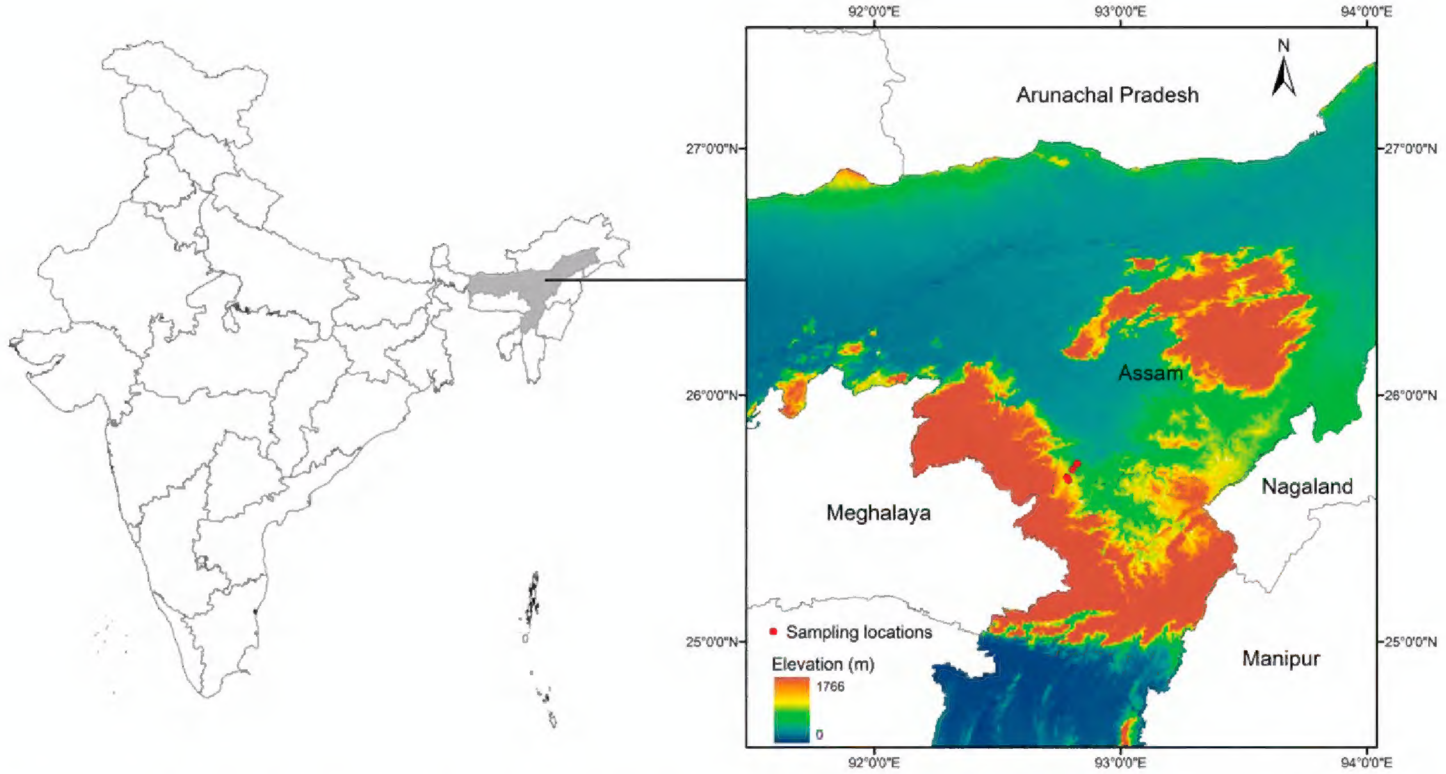

Figure 1. Map of the study area along with the sampling locations. The study was carried out in North Cachar hills along the river Kopili in Karbi-Anglong and Dima Hasao Sub-Division of North Cachar Forest Division in Assam, Northeast India.

in 5 m × 5 m and herbs (non-woody plants with a diameter of less than 10 cm) were sampled in 1 m × 1 m quadrats. All these two quadrats used for sampling shrubs and herbs (5 m × 5 m and 1 m × 1 m) were nested within the main quadrat of 10 × 10 m quadrat used for sampling trees, as per the standard methodology (Manish et al. 2017; Arora et al. 2024). A total of 40 quadrats were laid in this study (10 quadrats × 4 sites) to study the structure and composition of the forests in the study area.

Forest structure and composition

Using standard vegetation sample protocols, each sampling site was examined for constituent flora density, abundance, frequency and dominance for every vegetation strata (Curtis and McIntosh 1950). The sampling sites were then compared using the following vegetation indices: (i) species richness (SR) determined as the total number of species per sampling unit (Whittaker 1977), (ii) species diversity (SD) index (Shannon and Weiner 1963), (iii) evenness index (EI) (Pielou 1969), (iv) similarity index (SI) (Sorenson 1948), (v) Importance Value Index (IVI) (Curtis 1959). Apart from these, based on cbh, ten diameter classes (0–30 cm, 30.1–60 cm, 60.1–90 cm, 90.1–120 cm, 120.1–150 cm, 150.1–180 cm, 180.1–210 cm, 210.1–240 cm, 240.1–270 cm, >270 cm) of trees for all species were prepared and the density of the trees of each species in each diameter class was recorded. The regeneration state of species was determined based on the number of seedlings, saplings, and adults in each population (Khumbongmayum et al. 2005; Mishra et al. 2013).

Figure 2. Representative photographs of the vegetation in the sampling locations: **A** Forest view near Longphu village **B** forest view near Kala nala along the Kopili river **C** forest view near Panimore-Patharkore Basti **D** forest view in the upstream area above Longphu village.

Results

Overstorey composition and structure

A total of 445 individuals belonging to 52 tree species, 44 genera and 28 families were recorded from the North Cachar forest range. Euphorbiaceae and Moraceae were the dominant families having 5 species each followed by Magnoliaceae, Fabaceae and Salicaceae with 3 or > 3 species (Suppl. material 1: table S1). The total basal area occupied by the trees was 50.87 m^2ha^{-1} with a total density of 445 individuals ha^{-1} (Suppl. material 1: table S2). The dominant tree species were *Holarrhena pubescens* Wall. & G.Don with highest density (35 individuals ha^{-1}) and IVI values (IVI = 29.67). The highest basal area (19.78 m^2ha^{-1}) was recorded in *Protium serratum* Engl. (Suppl. material 1: table S2). As per IVI values, the other important species were *Mangifera sylvatica* Roxb. (14.69), *Homonoia riparia* Lour. (13.74), *Ficus benghalensis* L. (12.70) and *Machilus parviflora* Meisn. (11.86). The majority of the species found in the study area were natives, having origins in Southeast Asia, the Indian subcontinent, Himalayan and Indo-China regions (Suppl. material 1: table S2).

Understorey composition and structure

A total of 3870 individuals belonging to 31 species were recorded in sapling/shrub layer. Apart from these vascular plants, 157250 individuals belonging to 41 species were recorded in the herb/seedling layer. Of these, 7 species were categorised as pteridophytes belonging to 5 genera and 6 families. *Bambusa tulda* Roxb. and *Chromolaena odorata* (L.) R.M.King & H.Rob. were found to be the most frequent species with the highest number of individuals and the maximum IVI value (Suppl. material 1: table S3). Poaceae was the most species-rich and most important family in both sapling and seedling layers (Suppl. material 1: table S3). Similar to the trees, almost 80% of the dominant shrub and herbaceous species were natives with centre of origin in Indian subcontinent, Indo-China, Southeast Asia and the Himalayan regions (Suppl. material 1: table S3).

Population structure and regeneration status

The population structure of tree species depicted a reverse J-shaped curve in North Cachar hills (Fig. 3). Species richness and density decreased with increasing tree girth class. The highest stand density and species richness were recorded in the medium girth class (30–60 cm) and it gradually decreased with increasing size class up to 270 cm. Basal area values were highest (34.45 m^2ha^{-1}) in the 90–120 cm girth class and lowest (9.91 m^2ha^{-1}) in the 0–30 cm girth class. Population structure of a few dominant tree species such as *Homonoia riparia* Lour., *Lepisanthes senegalensis* (Poir.) Leenh. and *Machilus parviflora* Meisn. showed a reverse J-shaped curve (Fig. 4A–C) whereas *Protium serratum* Engl. (Fig. 4D) showed an interrupted population curve. In the present study out of 52 tree species, only 23% tree species exhibited good regeneration, 17% poor regeneration and 3% fair regeneration. Based on regeneration status, the presence of established saplings and seedlings in *Homonoia riparia* Lour., *Lepisanthes senegalensis* (Poir.) Leenh. and *Holarrhena pubescens* Wall. & G.Don species indicates that these species are good regenerating species. *Samanea saman* (Jacq.) Merr., *Colona floribunda* (Kurz) Craib, *Elaeocarpus tectorius* Poir., *Machilus parviflora* Meisn. and *Stereospermum chelonoides* (L.f.) DC. were found in a poor regeneration phase. Some rare and important species viz., *Aquilaria agallocha* Roxb., *Ixonanthes reticulata* Jack, *Lithocarpus elegans* (Blume) Hatus. ex Soepadmo, *Magnolia gustavii* King, *Protium serratum* Engl., *Balakata baccata* (Roxb.) Esser and *Terminalia citrina* (Gaertn.) Roxb. were found as non-regenerating species.

Discussion

Overstorey composition and structure

Tropical forest tree species richness varies from place to place due to changes in biogeography, habitat, and disturbance regimes (Naidu and Kumar 2016). The species richness for the tree strata (52) in the present study was lower compared to the adjoining tropical rain forest of Garo Hills which reported the presence of 153 tree species

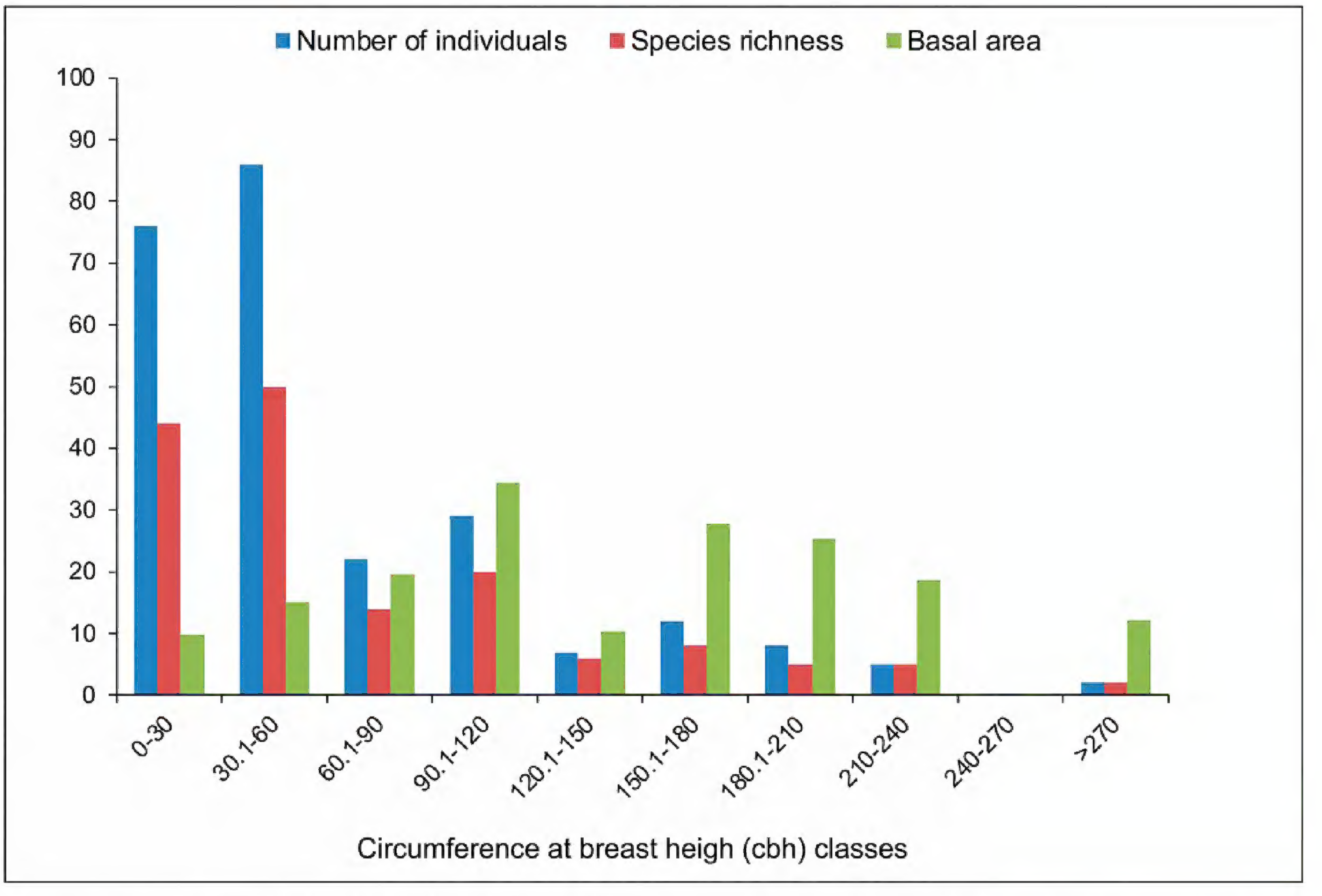

Figure 3. Number of individuals, basal area and species richness of tee species in different circumference at breast height (cbh) classes.

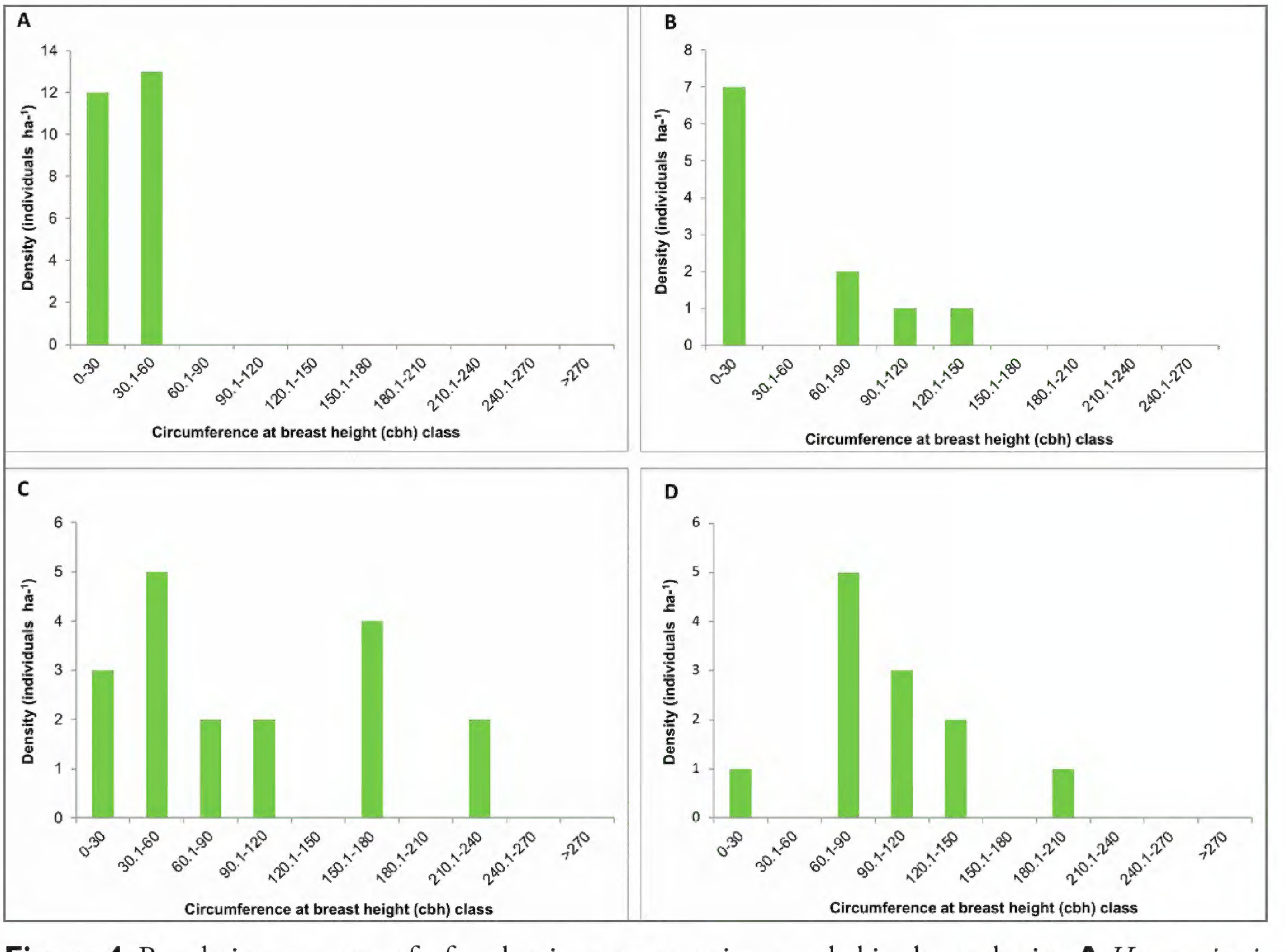

Figure 4. Population structure of a few dominant tree species recorded in the study site: **A** *Homonoia riparia* Lour **B** *Lepisanthes senegalensis* (Poir.) Leenh. **C** *Machilus parviflora* Meisn. **D** *Protium serratum* Engl.

(Kumar et al. 2006). Total tree density (445 trees ha-^{1}) and basal area (50.87 m^{2}ha-^{1}) recorded in the present study of rain forest are found within estimates from other studies of tropical wet evergreen forest in India (352–1173 trees ha-^{1}) and basal area 28–81 m^2 ha-^{1} (Sundarapandian and Swamy 2000). Tree density depends on several factors, including soil qualities, anthropogenic and natural disturbances, site history, tree size class, forest community, and age and condition of the forest (Kumar et al. 2006). The low basal area in the present forest stands may be due to few mature and buttressed tree species despite high annual precipitation (Lü et al. 2010). The causes of low basal area values may also be due to the extraction of timber species and prevailing shifting agriculture called 'Jhum' cultivation in the area (Bhuyan et al. 2003).

The density of saplings and seedlings was very poor or almost absent in the present study, especially of rare and endemic tree species. This may be due to the degree of disturbance or failure of germination and reproductive process (Sahu et al. 2012; Akindele 2013). Shannon-Wiener diversity index values recorded for tree species diversity in the present study (3.631) are higher than the tropical semi-evergreen forest of Assam (Sarkar and Devi 2014) and lie close to or within the range of Garo hills (Kumar et al. 2006). Earlier published reports have indicated that Simpson's index value ranges from 0.03–0.92 in the tropical forests of India (Bhuyan et al. 2003; Nath et al. 2005; Sarkar and Devi 2014). The values of Simpson's index in the present study (0.036) therefore conform with these findings. The eveness index (0.069) is comparable with other tropical wet evergreen forests of Arunachal Pradesh and the tropical evergreen forest of Meghalaya (Nath et al. 2005; Tynsong and Tiwari 2010). Lower evenness indicates that a few species dominate in the area, and the number of individuals within a species is not constant throughout the forest community (Sagar et al. 2003).

In the present study, *Homonoia riparia* Lour. was found to be one of the ecologically dominant species with high IVI value throughout the sampling sites in the mixed riparian semi-evergreen forest of North Cachar hills. This indicates a wide range of growth and adaptability of this species throughout the semi-evergreen forest. It was followed by other riparian species like *Protium serratum* Engl., *Mangifera sylvatica* Roxb., *Homonoia riparia* Lour., *Ficus benghalensis* L. and *Machilus parviflora* Meisn. In addition, some species confined themselves to river banks only like *Flacourtia jangomas* (Lour.) Raeusch., *Homonoia riparia* Lour. and *Ixonanthes reticulata* Jack. This may be due to their adaptation to specific habitats or niche and microclimatic preferences for growth.

Understorey composition and structure

Tropical forests with comparable overstorey ecological features may exhibit variations in the diversity and composition of understorey vegetation because of the interplay of several factors, such as stand age, overstorey composition, light, substrates, soil nutrients, and soil moisture (Webb et al. 1999; Su et al. 2019). With 72 species recorded in the area of 2000m^2 in four 0.1 ha plots, the understorey vegetation in the present study area was much more diverse than tropical evergreen forests in Kolli Hills. Earlier stud-

ies have reported 52 species in eight hundred $4m^2$ quadrats in 8 ha plots in Kolli Hills (Chittibabu and Parthasarathy 2000). Many factors can contribute to such variation in composition such as incidence of light, water availability, nutrient contents, soil depth, moisture, temperature, light quality, etc. (Su et al. 2019). Overall, the present study reveals that understorey could contribute a lot to the total species richness of tropical rainforests and should not be neglected for biodiversity management and assessment programs by forest policymakers. Equal emphasis should be placed on documenting the overstorey and understorey vegetation in the tropical rainforests.

Population structure and regeneration status

The distribution of tree size classes has frequently been used to depict a forest's population structure (Saxena et al. 1984; Rao et al. 1990). In the present study, girth class frequency showed a reverse J-shaped population curve, which is similar to reported for the other forests of Northeast India (Bhuyan et al. 2003; Mishra et al. 2004; Sarkar and Devi 2014). A reverse population curve indicates an evolving or expanding population in the forest (Sarkar and Devi 2014). However, the presence of a smaller number of trees in the small girth classes (< 20 cm) indicates that the forest is not sustaining itself due to inefficient management and recurrent human disturbance (Kunwar and Sharma 2004). Availability of seeds, seed dormancy and competition among species for space, light and water are also cited as other factors for the non-regeneration of species (Holl et al. 2000; Wijdeven and Kuzee 2000; Mishra et al. 2013). Though no data is available on seasonal variation in soil or exposure and drainage characteristics, we believe from our field experience that it can also be a strong cause of mortality for seedlings and young trees.

Conclusions

Our present study reveals that understorey should be fully considered for assessing biodiversity in tropical forests as the sapling/shrub and herb/seedling layers may hold as many species as the tree layer. However, these forest stands have been under biotic pressure in recent years. Due to many anthropogenic activities such as agriculture, grazing by domestic cattle, mining, hydropower projects, species-rich habitats are gradually being converted into degraded areas. The practice of shifting cultivation, locally referred to as 'Jhum' adds to the existing threat. The practice of monoculture plantations of betelnuts, rubber, etc., which additionally puts pressure on the natural forests, has also witnessed a rising trend in recent years in the study area. To conserve the regional plant diversity in such biodiversity-rich areas, quantitative analysis of tree and shrub species diversity especially rare, endemic and globally threatened species will be useful from a conservation and forest management point of view considering the proximity of these forest stands to local tribal villages and modern highways. There is an urgent need to protect the Cachar hills from increasing anthropogenic disturbances.

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Supplementary material 1

Supplementary data

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Data type: pdf

Explanation note: **table S1.** List of tree families with the total number of genera and species in the study area. **table S2.** Density (D = individuals ha-^{1}), basal area (BA= m2 ha-^{1}), Importance Value Index (IVI) and regeneration status (RS) of adult tree species in the study area. The notation 'NR' in the table represents non-regenerating species. **table S3.** Density, frequency and importance value index (IVI) of the 12 most dominant species in the shrub/sapling and herb/seedling layer in the study area.

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